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The southernmost evidence for an interglacial transgression (Sangamon?) in South America. First record of upraised Pleistocene marine deposits in Isla Navarino (Beagle Channel, Southern Chile)

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ABSTRACT

Marine beach shell deposits recording a pre-Holocene marine transgression have been found at the southern shore of the Beagle Channel, Isla Navarino, Chile. These shelly deposits were dated by AMS at 41,700 ^{14}C years B.P., which clearly indicates a Pleistocene age. A sample of wood underlying the marine deposits yielded an infinite age (>46.1 ^{14}C ka B.P.). If the date on the shells is considered as a minimum, infinite age, together with the elevation of these marine units above present mean tide sea level (at least 10 m a.s.l.) they may be considered as deposited during the Last Interglacial, of Sangamon age (Marine Isotope Stage -MIS- 5e) or during a younger phase of MIS 5. The fossil content of this unit is similar to the fauna living in this region today, supporting also an Interglacial palaeoenvironment interpretation. If this interpretation and the dating proposal are correct, this is the first reported record of Sangamon deposits in the Beagle Channel and the southernmost Last Interglacial site (MIS 5) in South America.

KEYWORDS **Interglacial. Marine beach shell deposits. Mollusks. Tierra del Fuego. Southernmost South America.**

INTRODUCTION

The Beagle Channel (Tierra del Fuego, Argentina and Chile; lat. 55º S, long. 67º-70º W; Fig. 1) is a sea flooded glacial trough, which was occupied by marine waters after deglaciation in Late Glacial or earliest Holocene times, that is, sometime in between 15,000 and 9,000 ^{14}C years ago (Porter et al., 1984; Rabassa et al., 2000;

Bujalesky, 2007; Bartole et al., 2008). This glacial valley was formed by a discharge outlet glacier, the "Beagle Glacier", descending from the Darwin Cordillera mountain ice cap (lat. 54º30' S, long. 69º-71º W; Chile). This still surviving ice body was the southernmost portion of the Patagonian Ice Sheet during the Pleistocene (Rabassa et al., 1992, 2000). The "Beagle Glacier" occupied this trough during at least the last two major glaciations. These glacial episodes were originally identified by Caldenius (1932) and later named as Lennox Glaciation (Middle Pleistocene, Marine Isotope Stage -MIS- 6 or older) and Moat Glaciation (Late Pleistocene, MIS 4-2) by Rabassa et al. (1992, 2000).

Both the northern (Argentina) and southern (Chile) shores of the Beagle Channel have extensive outcrops of Holocene marine terraces at various altitudes (Rabassa et al., 2000; Bujalesky, 2007) but no Pleistocene marine deposits had yet been discovered. In previous papers, Rabassa et al. (1990, 1992, 2000) reported very scarce, fragmentary marine shells in the lower till unit at Isla Gable (lat. 55º S, long. 67º30' W; Argentina). These authors interpreted them as coming from Late Pleistocene marine deposits that had been overriden by the "Beagle Glacier" during the Last Glaciation advance (MIS 4-2), which incorporated them as part of its sedimentary load, but the original marine deposits were never found. The Last Glaciation Maximum (LGM) in the region would have peaked around 25 ka B.P., based upon a correlation with the Magellan Straits sequence (McCulloch et al., 2005), and not later than 15 ka ^{14}C B.P., based on the radiocarbon age of the basal peat at the Harberton Bog (Argentina, lat. 54º52' S, long. 67º53' W; 14,640 ^{14}C years B.P.; Heusser and Rabassa, 1987; Heusser, 1989). Thus, the existence of a Pleistocene marine environment along the Beagle Channel depression had been already suggested based on reasonable evidence (Rabassa et al., 2000).

During recent archaeological studies at Isla Navarino (October-November 2005), two of us (C. Ocampo and P. Rivas) found a new locality of marine upraised beaches at the northern shore of Isla Navarino (lat. 55º S, long. 67º15' W; Chile), surveyed the section and sampled the identified units. The marine deposits were exposed by the construction of a new road along the coast, east of the town of Puerto Williams (lat. 55º S, long. 67º30' W; Chile; Fig. 1).

This contribution deals with the above-mentioned findings and the investigations that confirmed the existence of a Pleistocene marine environment record in the Beagle Channel (Fig. 1). Although a full systematic account of the whole Pleistocene fauna of this site will require additional studies, the available data justify their publication together with our interpretations. The primary goal of this paper is to provide an overview of this interesting fossiliferous site, which constitutes a new record for the marine Pleistocene of southernmost South America.

GEOLOGICAL SETTING. THE CORRALES VIEJOS SECTION

The geology of Tierra del Fuego, where Isla Navarino is located, has been the subject of research from long time ago (see Menichetti and Tassone, 2007, 2008 and cites therein). The characterization of the late Paleozoic-Mesozoic metamorphic complexes, the study of the Mesozoic-Cenozoic stratigraphy and of the ancient to recent tectonic processes in the region (Hervé et al. 2008, Olivero and Malumián, 2008, Menichetti et al., 2008 and other papers therein) have resulted in a noticeable increase of the geological knowledge on this region. The Pleistocene to Holocene record has also been the subject of many studies that have focused on the recent quaternary evolution of this remote southernmost South America area (Rabassa et al., 1992, 2000).

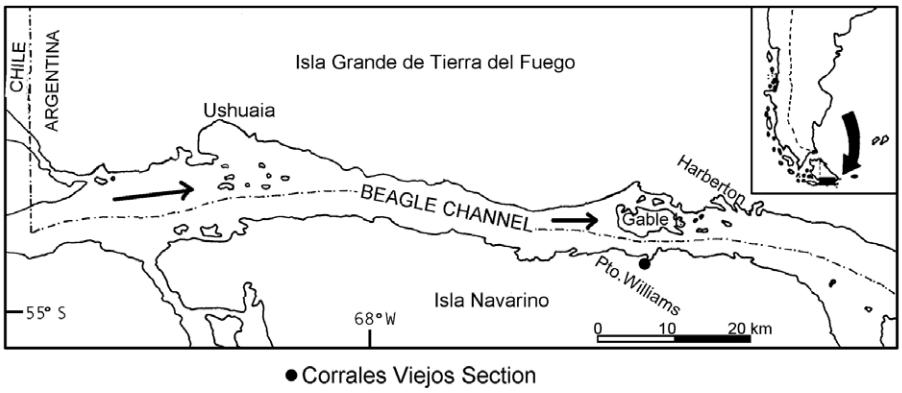


FIGURE 1 | **Location map of the Corrales Viejos Site. Note the position of the site close to the town of Puerto Williams. The arrows indicate the ice flow direction of the ancient Beagle Glacier.**

Holocene successions and their related faunal assemblages occur in many places along the northern and southern coasts of the Beagle Channel (e.g., Porter et al., 1984, Rabassa et al., 1986, 2000; Gordillo, 1992; Gordillo et al., 1992, 2005). However, deposits corresponding to the Pleistocene marine transgressions seemed to have not been preserved in the Beagle Channel region due to the intense erosive effect of the Last Glaciation (MIS 4 to 2; Rabassa et al., 2000). Though the exact age of the Pleistocene Beagle glacial valley formation is still unknown, it is herein assumed that during glacial periods the ice excluded much, if not all, of the benthic marine fauna inhabiting the marine environment in the present Beagle Channel valley or its original depression. During such glacial events, sea shore was located at least several tens of km eastwards due to glacioeustatic sea level lowering.

Only two previous poorly preserved fossil records recovered from till deposits in the vicinity of the city of Ushuaia (lat. 54º50' S, long. 68º W; Argentina; Rabassa et al., 1986) and in Isla Gable (Rabassa et al., 1990; Gordillo, 1990), indicated that the Beagle Channel had been occupied by seawater at least once before the Last Glaciation. A different situation occurs along the northeastern Atlantic coast of the Isla Grande of Tierra del Fuego, where several lithostratigraphic units represent different Pleistocene interglacial episodes (Bujalesky et al., 2001; Bujalesky, 2007). Among them, La Sara Formation (at 14 m a.s.l.), located near the city of Río Grande (lat. 53º45' S; long. 67º 30' W; Argentina), is attributed to the Late Pleistocene (Codignotto and Malumián, 1981), and it has been correlated with the Last Interglacial period, Sangamon Stage, MIS 5e (Bujalesky et al., 2001; Bujalesky, 2007).

Stratigraphy

The Corrales Viejos Site is located at approximately lat. 55º S, long. 67º15' W (Fig. 1). Mean tide amplitude in the area is 2-3 m. The base of the section is at an elevation of 7.3 m above high tide level (Fig. 2). Mean tide amplitude in the area is 2-3 m.

There is no field evidence of post-depositional glaciotectonic deformation or lateral displacement which could have been forced as the ice overrun this site after the deposition of the marine layers. Likewise, there is no evidence that landsliding or slumping would have affected this locality. Nevertheless, even if any of these latter processes would have affected the area, the original topographical position of the marine sediments would have been even higher in the landscape than today.

Depositional environment

The visible base of the section is composed of continental sediments, probably of fluvial, lacustrine and marshy origin (Units 1 to 4), nearby a fully developed *Nothofagus* forest. These layers are covered by Unit 5, which represents an upraised marine beach, corresponding to a marine transgression. When sea level receded from this site, a terrestrial environment was established

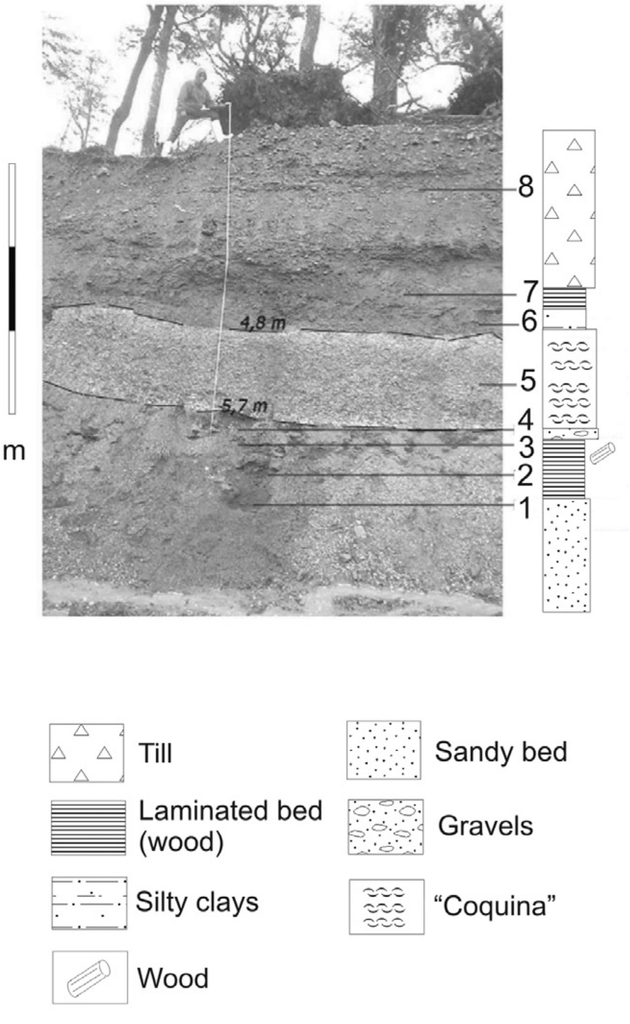


FIGURE 2 | **Stratigraphic section of the raised Pleistocene beach deposits at Corrales Viejos. 1: Base of the section. Visible base is below 6.30 m from the top. Dark greenish, greyish sandy beds. 2: 0.20 m. Greyish clayey silt which breaks in small blocks. 3: 0.25 m. A silty-sandy layer including tree trunks and *Nothofagus* spp. wood fragments. (Sample 4). 4: 0.15 m. Greyish silty gravels. (Sample 3). 5: 0.9 m. Marine beach deposits, a layer composed entirely of broken and rounded marine shell fragments, reduced to fine gravel size by wave action. (Sample 2). 6: 0.30 m. Greyish clayey-silty beds which separates in small blocks. (Sample 1). 7: 0.5 m. Greyish, laminated, fine grained beds, containing decomposed wood fragments. 8: 4.0 m. Till, composed of a medium sized gravel, with a sandy-clayey matrix, showing no internal stratification. The cobbles and pebbles are irregularly distributed in the unit, showing a distinctive yellowish orange color, due to weathering.**

again, with soil development and forest recovery (Units 6 and 7). Finally, an advancing glacier covered the section, partially eroding the top of it and burying the marine beach units (Unit 8). Most likely, the ice thickness was smaller at the margins of the ancient glacial trough, which reduced its erosive force, thus allowing preservation of the marine beds.

Radiocarbon dating and age discussion

A radiocarbon date on selected fragments of marine shells obtained from the sample of Unit 5 (Fig. 2, Sample 2) was measured by AMS ^{14}C technique at the NSF-Arizona AMS Laboratory (University of Arizona). It yielded an age of 41,700 ± 1,500 years BP (AA 69648), with a ∂^{13}C value of +0.6. Likewise, a sample of *Nothofagus* sp. wood coming from Unit 3 was also dated at the same laboratory and using the same technique (AA 75295), obtaining and age of >46,100 years B.P., with a ∂^{13}C value of -28.5.

Considering that the dated materials in the first sample are old marine shell fragments and the obtained age is close to the accepted reliability boundary of the AMS dating method, the given age could be interpreted as (a) a correct absolute age or (b) if contaminated with a very small proportion of modern C, as an infinite age, beyond the lowest limit of the radiocarbon dating technique. In any case, the dated shells are of undoubtedly of pre-Holocene age, thus corresponding to the Late Pleistocene or even an older age. The second date on a wood sample clearly goes beyond the radiocarbon method dating boundary, and it is considered as infinite.

PALEOBIOLOGICAL CONTENT

Taxonomy

The fossil fauna identified in the shelly bed sample is quite diverse and comprises at least 25 different mollusk species (13 bivalves and 12 gastropods) and other invertebrate groups as bryozoans, echinoids and cirripeds. Many taxa are represented by fragments of macrofossils or small tiny shells sometimes difficult to identify. A preliminary list of this fauna is reported in Table 1 and part of the material collected is illustrated in Fig. 3. The paleontological material mentioned here is housed in the Centro de Investigaciones Paleobiológicas (CIPAL), Universidad Nacional de Córdoba, Argentina, under the prefix CEGH-UNC.

TABLE 1 **Preliminary list of taxa identified from the Corrales Viejos site, Isla Navarino, Chile.**

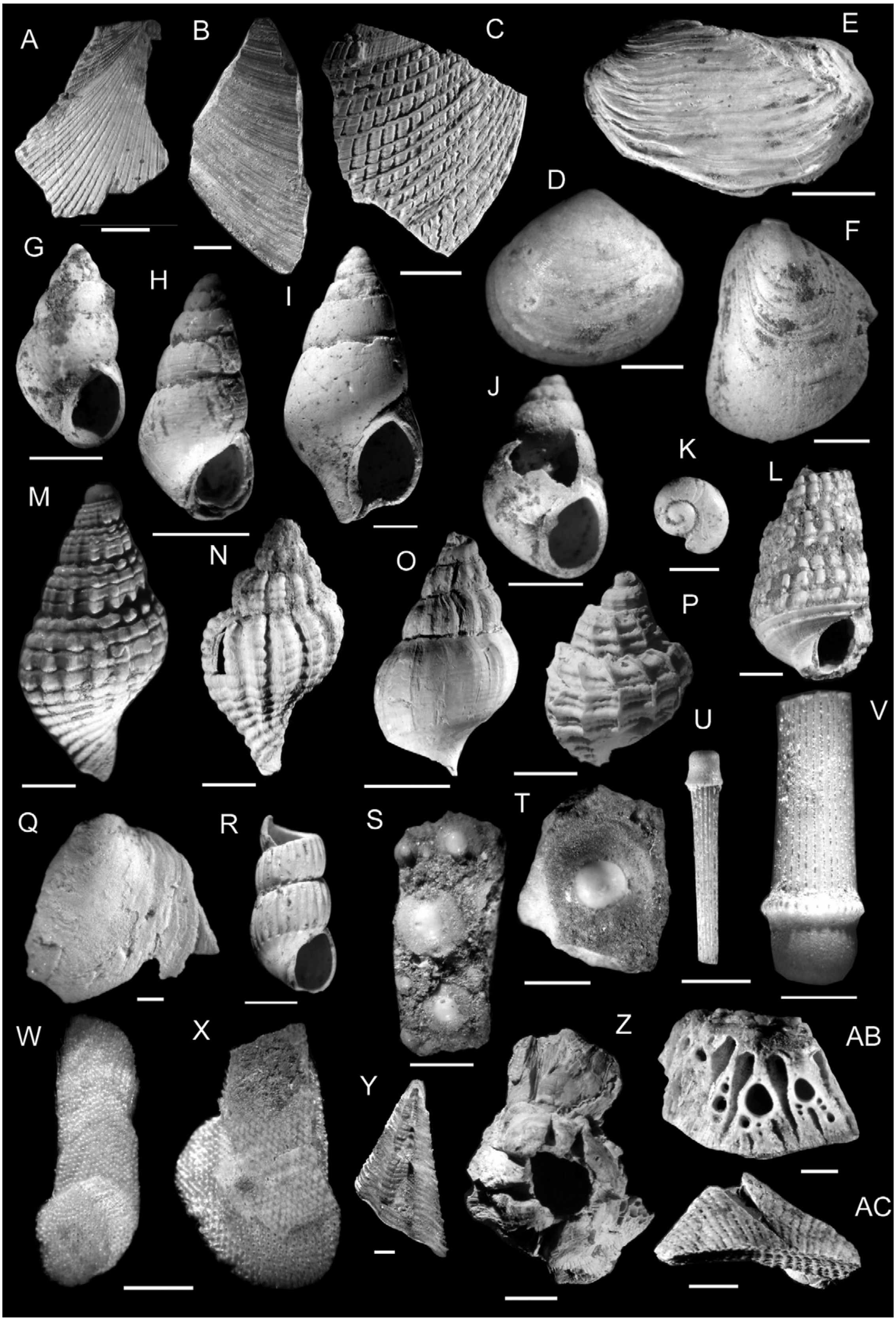
MOLLUSCA
Bivalvia
- *Nucula* sp.
- *Aulacomya atra* (Molina, 1782)
- Mytilidae (?Mytilus edulis chilensis Hupé *in* Gay, 1854)
- Pectinidae (?Zygochlamys patagonica (King and Broderip, 1832))
- *Rochefortia rochebrunei* Dall, 1908
- *Neolepton concentricum* (Preston, 1912)
- *Neolepton* spp. (2)
- *Hiatella* sp.
- Veneridae sp 1, fragments, (?*Venus antiqua* (King and Broderip, 1832))
- Veneridae sp2, fragments
- Indeterminable bivalves

Gastropoda
- Trochidae (?*Margarella violacea* (King and Broderip, 1832))
- Rissoiform gastropods (3)
- *Crepidula* cf. *dilatata* Lamarck, 1822
- *Cerithiella* sp.
- *Trophon geversianus* (Pallas, 1769)
- *Xymenopsis muriciformis* (King and Broderip, 1832)
- *Pareuthria* ?*plumbea* (Philippi, 1844)
- *Glypteuthria* sp.
- *Turbonilla* cf. *smithi* Strebel (Pfeffer, MS), 1905
- Indeterminable gastropods

ECHINODERMATA
Echinoidea
- Isolated spines and test elements (?*Loxechinus albus*)

ARTHROPODA (CRUSTACEA)
Cirripedia
BRYOZOA (undetermined bryozoans)

FIGURE 3 **A) Pectinidae (?*Zygochlamys patagonica*), fragment (CEGH-UNC 22786). B) Mytilidae (?*Mytilus edulis chilensis*), fragment (CEGH-UNC 22796). C) Veneridae (?*Venus antiqua*), fragment (CEGH-UNC 22768). D) *Neolepton* sp. (CEGH-UNC 22820). E) *Hiatella* sp. (CEGH-UNC 22826). F) *Aulacomya atra*, juvenile specimen (CEGH-UNC 22821). G) Rissoiform gastropod, sp1 (CEGH-UNC 22777). H) Rissoiform gastropod, sp2 (CEGH-UNC 22776) I) *Pareuthria ?plumbea* (CEGH-UNC 22775). J) Rissoiform gastropod, sp3 (CEGH-UNC 22783). K) ?*Margarella violacea* (CEGH-UNC 22782). L) *Cerithiella* sp. (CEGH-UNC 22828). M) *Glypteuthria* sp (CEGH-UNC 22723). N) *Xymenopsis muriciformis* (CEGH-UNC 22823). O) ?*X. muriciformis* (CEGH-UNC 22774). P) *Trophon geversianus* (CEGH-UNC 22785). Q) *Crepidula* cf. *dilatata* (CEGH-UNC 22780). R) *Turbonilla* cf. *smithi* (CEGH-UNC 22784). S-T) Echinoid fragments, test elements (CEGH-UNC 22791). U-V) Echinoid fragments, isolated spines (CEGH-UNC 22790). W-X) Bryozoans (CEGH-UNC 22789). Y-AB) Cirripeds Y. (CEGH-UNC 22794). Z) (CEGH-UNC 22795). AA) (CEGH-UNC 22793). AB) (CEGH-UNC 22792). Scale: 1 mm (except A, B, C and Z). Scale: 5 mm (A, B, C and Z).**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Mytilids dominate over other mollusks, and together with the cirripeds represent more that the 75% of the fossil materials. Many other taxa are represented by low number of specimens, sometimes broken, that makes their identification difficult. They belong to different families, including pectinids, venerids, muricids and rissoiform gastropods, among others. The rissoiform gastropods -very difficult to classify on shell characters alone (see Ponder and Worsfold, 1994) - include at least 3 different species. The specific assignment of *Neolepton* specimens will require a description using scanning electronic microscope (MEB) to be performed in the future. The echinoids are represented by isolated spines and test elements. They do not show differences when comparing with those belonging to one of the living species in the region and probably represent the same taxa (i.e., *Loxechinus albus*).

Taphonomy

The marine shelly beds (Unit 5) yielded an abundant fossil fauna dominated by calcareous macro- and microfossils. The macrofossils show frequent signals of fragmentation but low levels of abrasion (Figs. 3A, B and C). These characteristics suggest that the fossils that compose this assemblage have moved only a short distance away from their original life habitats. Cirripeds (Figs. 3Y-AB) dominate over other macroinvertebrates, followed by macromollusks (especially mytilids). The microfossils recovered from the marine shelly beds (Unit 4) also show signs of fragmentation (e.g., Figs. 3L, O and P-V) and may represent reworked shallow-marine faunas. A detailed study of the microfossil content will be performed in the future, based on more extensive sampling.

Palaeoenvironmental remarks

All identified species still live today in the Beagle Channel. The macrofauna represented in the fossil assemblage is strongly dominated by sessile suspension feeder epifauna (i.e., cirripeds, mytilids), intermixed with some infaunal elements (i.e., fragments of venerids). This situation suggests the availability of hard substrate which permitted the development of the epifauna, and soft sub-environmental conditions, which allowed the existence of burrowing clams. This biota is typical of modern environments in this region.

We have compared this site, dominated by epifaunal elements, with the La Sara Formation (Fm), a marine unit of Last Interglacial age (MIS 5e) which is a likely time equivalent to the section studied herein. The La Sara Fm. is quite homogeneous with a low number of species and dominated by infaunal bivalves (i.e., venerids; see Gordillo, 2006). It may be interpreted that these differences can be related to the prevalence of different regional conditions (e.g., bottom geomorphology, rock substratum, current velocity) in both regions which allow for the development of different local communities under similar climatic conditions.

The presence of barnacles also suggests the existence of strong bottom currents and shallow waters. However, most of the mollusk species recovered are able to distribute over a wide depth range from few to several meters.

At the time of deposition of the marine shell unit of Corrales Viejos, the Beagle Channel was occupied by the sea at least in its easternmost portion. It is still impossible to estimate the extent of westward penetration of the sea, and even more difficult to conclude if it was a fjord or channels open to both austral seas. The coeval deeper water marine deposits in the channel, if they ever existed, were mostly likely wiped away by the advancing Last Glaciation ice. Additional work is needed to understand these paleogeomorphological circumstances.

DISCUSSION AND CONCLUDING REMARKS

From a paleontological viewpoint, the Beagle Channel is of great interest for biogeographic and paleobiogeographic studies because this region represents a transitional area between the Atlantic and Pacific oceans, and also because of its proximity to the Drake Passage and the Circumpolar Antarctic Current. The study of the fossil Quaternary biota in the region can be a clue to understand the origin and migration routes of the fauna living today in the area and how it was affected by past positional changes of the Circumpolar Current.

The Corrales Viejos Section is the first reported record of in-situ Pleistocene marine sediments in the Beagle Channel region. All pre-existing geological information about marine beds in the area is strictly related to Holocene raised beaches and other coastal deposits.

A Pleistocene age for these sediments is inferred from the following evidence:

1. An AMS ^{14}C date of 41.7 ± 1.5 ka B.P. on marine shells, which may be correct or contaminated by younger carbon, in the latter condition suggesting an infinite age, but in any case of undoubtedly pre-Holocene age.

2. An AMS ^{14}C infinite date of >46.1 ka B.P. on fossil wood underlying the marine beds but clearly forming part of the same transgressive sedimentary sequence.

3. The elevation of the shelly layers at >10.0 m a.s.l. is too high to be assigned to the Holocene, as shown by pre-

vious studies in the eastern portion of the Beagle Channel (Gordillo et al., 1992; Rabassa et al., 2004). Therefore, these marine units are undoubtedly of Pleistocene age.

4. The studied section is covered by till, which could have been deposited only by a Pleistocene glacier (Holocene glaciation was restricted in this region only to the mountain summits; Rabassa et al., 2000), most likely during the Moat Glaciation (MIS 2 or even MIS 4). Glaciers had already vanished from this area during Late Glacial times (Rabassa et al., 2000).

5. Considering the available radiocarbon ages, these marine deposits could be assigned to an interstadial event of the Late Pleistocene, either to the beginning of the Mid-Wisconsin Interstadial (MIS 3) or most likely, to the Last Interglacial (Sangamon, ca. 125 ka B.P., MIS 5e) or to other warmer events during MIS 5. However, sea level was during MIS 3 clearly below present sea level, perhaps at around the -40/-50 m isobath. If this should be the case, it would have required a very strong, fast and steady tectonic or glacioisostatic uplift of Navarino Island since MIS 3, for which there is no evidence within the entire region.

6. Alternatively, assuming contamination of the marine shells with younger radiocarbon, an infinite absolute ^{14}C age of > 41 ka B.P. may be interpreted for these units and, most likely, a Last Interglacial age corresponding to the MIS 5e (Sangamon Interglacial) or other later times during MIS 5. This is fully supported by the infinite age of the dated *Nothofagus* wood fragment. During the Sangamon Interglacial epoch sea level was basically at the same elevation as today, and the present elevation of these deposits, mostly due to seismotectonic uplifting, is coherent with what we know about the La Sara Fm. (of undoubtedly Sangamon age) along the Atlantic Ocean coast of Isla Grande de Tierra del Fuego (Rabassa et al., 2000; Bujalesky et al., 2001; Bujalesky, 2007, and other papers therein).

7. There is not any kind of available evidence in this region to suggest a pre-Sangamon age for these units at the present state of our knowledge.

For all these reasons, a Last Interglacial age (Sangamon Stage; MIS 5e, or any of the later events during MIS 5) is favoured for the sediments found in this section.

At the moment these shelly marine deposits represent the richest and most diverse fossil marine Pleistocene record of Southernmost South America and the closest locality to the Drake Passage, the Antarctic Peninsula and the Circumpolar Antarctic Current. This new finding opens important windows on the paleoclimatic and the faunal history of the Beagle Channel during the Pleistocene. Further integrated studies, with additional surveying and sampling and including other proxy elements (diatoms, pollen and phytoplancton analysis, micropaleontology, dendrochronology, etc.), will give a more complete and precise information over these high-stand sea level deposits and the knowledge of the biota that inhabited this region during Pleistocene times.

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